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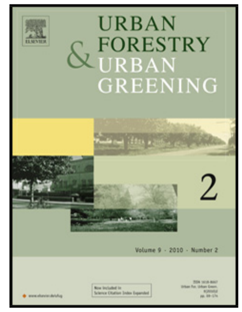

Title: What makes urban greenspace unique – relationships between citizens' perceptions on unique urban nature, biodiversity and environmental factors

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Title: What makes urban greenspace unique – relationships between citizens' perceptions on unique urban nature, biodiversity and environmental factors

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Highlights

- Biodiversity of an urban forest patch positively correlates with its perceived uniqueness
- People prioritize the conservation value of large, isolated forests, with less-built but densely-populated urban surroundings
- Some environmental factors, e.g., connectivity and canopy cover, have distinct effects on biodiversity and people's perception

Abstract

Maintaining urban greenspace is important for stimulating diverse human-nature interactions. Yet, which greenspace to prioritize for conservation under threat of urban densification is a major planning challenge. Besides ecological knowledge and objective use, people's subjective perception or opinion of urban greenspace has been emphasized in assessing the conservation value of urban greenspace and guiding present-day urban planning. Better understanding on people's perception of urban greenspace and its influencing factors are, therefore, needed. Here we employ a Public Participatory Geographic information System (PPGIS) survey on "unique urban nature" in the city of Helsinki to explore people's perceived uniqueness (i.e., perceived conservation value) of urban forest patches. We use generalized linear modeling (GLM) and structural equation modeling (SEM) to estimate the relationship between this perceived uniqueness and measurable conservation factors, specifically four biodiversity indicators (BDIs) and seven environmental factors characterizing vegetation structure, landscape features and urban context of the forest patch. Results show that biodiversity has a strong positive impact on perceived uniqueness (PU), while environmental factors have variable impacts on PU, either directly or indirectly through their impacts on biodiversity. While the size and surrounding population density of an urban forest are positively correlated with both biodiversity and PU, its connectivity, surrounding constructed land-use, and canopy cover exhibit negative correlations with PU. Our results highlight the importance of biodiversity in affecting PU both as a direct influencing factor and as a mediator of the impact of environmental factors. We detected distinct effects of environmental factors (e.g., connectivity, canopy cover) on biodiversity and PU, implying different responses of biodiversity and PU to these

factors, and a potential trade-off between biodiversity (natural conservation value) and people's conservation value when managing urban forests.

Key words: canopy cover, patch size, PPGIS, Structural Equation Modeling, urban forest

Introduction

Urbanization causes huge changes in peoples' lifestyles, values and living environment. Due to limited time and access to greenspace, there is a risk that cultures become separated from nature (Miller, 2005), especially given that more than half of the earth's human population live in urban areas. Many urban residents are no longer in daily contact with nature and local biodiversity, which can cause many mental and physical health problems (Hartig et al., 2014), but also biocultural homogenization (Celis-Diez et al., 2017). This phenomenon has a drastic influence on people's perceptions, images and knowledge about nature and its diversity (Soga & Gaston, 2016). On the contrary, cities can be biologically and culturally diverse places offering many possibilities for nature experiences or biodiversity protection through active place-making (Vierikko et al., 2016). To this end, maintaining "enough" greenspace in cities to stimulate diverse human-nature interactions is critical (Kabisch, Qureshi, & Haase, 2015). However, urban densification poses a real threat to the availability of such greenspaces (Haaland & van den Bosch, 2015). To identify urban greenspace with high conservation values and its influencing factors is, therefore, important for their long-term maintenance and planning.

High biodiversity urban greenspaces are often considered of high conservation value (Dearborn & Kark, 2010; Secretariat of the Convention on Biological Diversity, 2012). Meanwhile, people's benefits from urban greenspaces are also critical for assessing the conservation value of the space

(Rall et al., 2017). People's benefits include both objective use of the greenspace (e.g. walking dogs and jogging) (Lin et al., 2014) and subjective perception (e.g. people's feeling of well-being and uniqueness, and emotional attachment) (Buchel & Frantzeskaki, 2015). In particular, people's perception of urban greenspace and its influencing factors has drawn recent attention, since the public has a strong capacity to identify cultural services where they live (Brown, Montag, & Lyon, 2012). However, the integration of these public perceptions and opinions about urban nature with expert-oriented data and knowledge to support urban land-use is rather scarce (Faehnle et al., 2014).

Several factors have been recognized to influence people's perception of urban greenspace. Studies have revealed a strong relationship between field-measured biodiversity and human-perceived psychological benefits (Fuller et al., 2007; Luck et al., 2011; Pett et al., 2016). In addition, some environmental factors that can be adjusted through urban planning and management, such as landscape features, urban context and vegetation structures of an urban greenspace, have also been found important in determining people's perception of an urban greenspace. For instance, residents of neighbourhoods with small and interspersed greenspaces feel more satisfied with the public greenspace (Soga et al., 2015). Visitors perceived more benefits of greenspaces in peri-urban areas than in urban areas (Carrus et al., 2015). Different vegetation densities of urban greenspace also result in different preferences (Suppakittpaisarn et al., 2018) and perceived recreational appropriateness (Zhang et al., 2013). Since these environmental factors have also been reported to impact the biodiversity of urban greenspace in various studies (Beninde, Veith, & Hochkirch, 2015; Latta et al., 2013; Morelli et al., 2017), it is expected that they may also have influenced people's perceptions of urban greenspace indirectly through their effects on biodiversity.

Only a few studies on people's perceptions enrolled an exclusive mapping of the greenspace available in the city (Ives et al., 2017), and city-scale investigations of their influencing factors are lacking. Public participatory mapping is a useful method to identify and measure subjective knowledge, meanings and values people have about, e.g. their living environment (Tyrväinen, Mäkinen, & Schipperijn, 2007). Internet-based participation GIS tools (e.g. public participatory geographic information system (PPGIS)) are emerging to involve a wider range of respondents and to collect peoples' valuation and perceptions more precisely (Kyttä et al., 2013). It, therefore, has great potential to be applied at the city-scale to analyzing people's perceived benefits of an urban green area and their influencing factors for urban planning (Brown & Fagerholm, 2015; Haase et al., 2014).

In this study, we explored the perceived conservation value (i.e., unique urban nature) by exploring a PPGIS survey on "unique urban nature" in the city of Helsinki. We restrict our analysis to one type of urban greenspace – urban forest, which is the dominant urban greenspace in the city of Helsinki and has been less studied compared to other types of urban greenspace (e.g., urban parks). "Urban forest" in our study refers to patchy woodlands in urban areas, in which shrubs and young seedlings are extensively managed, and tree structure and the ground layer are similar to that of natural forests (Lehvävirta & Rita, 2002). In Helsinki, urban forest are frequently used by residents for their daily leisure or exercise (Neuvonen et al., 2007), and the management is mainly for the purposes of biodiversity conservation and recreation (Saukkonen, 2011). We analyze which kinds of urban forests citizens identify as "unique" and if their perceptions have linkages with expert-oriented valuation of levels of biodiversity and measured environmental factors and how. This study is expected to provide insights into the variation of people's perception of unique urban nature (i.e., high conservation value) at the city-scale and provide better understanding to support urban greenspace planning and management.

Material and methods

Study site

The study was performed in the city of Helsinki, southern Finland (60ºN, 24ºE). Biogeographically, the region is situated in the hemi-boreal forest zone. The urban green infrastructure (UGI) of Helsinki consists of semi-natural habitats (e.g., forests, rocks) taking up 64% of the UGI area, 17% of anthropogenic habitats (e.g., meadows, ruderal) and 19% of constructed habitat (e.g., parks, cemeteries) (Vierikko et al., 2014). Urban forests, as the dominant greenspace type in Helsinki, are spread all over the city except the very center with varying sizes (from less than 1 ha to over 1 km^2) and structure (see Fig. 1).

The municipality of Helsinki had 643 000 inhabitants by the end of 2017 with a large urban forest area per capita of 80 m^2 (Vierikko, Fors, & Saarinen, 2015). However, the population of Helsinki will grow by up to 70 000 residents in the coming decades (City of Helsinki, 2018). This results in pressure for new built areas at the expense of urban forest.

Citizens' perceptions of unique urban nature

A PPGIS dataset from a planning-oriented survey was employed in this study. In preparation of the new Helsinki 2050 Masterplan, the city carried out a map-based online survey to collect citizens' perceptions of the status and expectation of the built and green area in the city (Kahila-Tani et al., 2016). The survey website (http://yleiskaava.maptionnaire.com/en/) lists 16 questions that ask respondents to mark places of interests on the city map (in Finnish, Swedish or English). Six questions concern areas for residential, commercial and industrial use, 5 questions are about transportation, 3 questions are about urban areas that are poorly managed, and only 1 question is particularly relevant to urban greenspace, which asks the respondents to mark sites that are "unique city nature just as it is". By answering this question, the respondents may have marked a forest patch because of its unique vegetation or sense of place, frequent use, or even subjective attachment. Although the motivation of the marks likely varies, we considered them to be a good direct measure of citizens' general perception of unique urban nature that may indirectly reflect the conservation value of urban nature from a citizen's point of view.

The survey was advertised primarily through social media (Twitter and Facebook) and local newspapers, and was opened from November to December of 2013. It received 1403 respondents with 4816 marked locations of "unique urban nature". Respondents are from districts all over the city (Supplementary material, Fig. S1). Since this is an internet-based survey, young and middle-aged citizens (aged 20-39) were over-represented, 44% of survey respondents were in this age group while only 32% of city residents are in this age group. Nevertheless, since young and middle-aged inhabitants predominate the population of Helsinki, we consider demographics of the survey as representative of the majority of the population.

We restricted our analysis to urban forest and only extracted the marks of the respondents located within urban forests according to the UGI Map of Helsinki. In total, 865 independent forest patches, which are separated by other types of land-use or vehicular roads, are identified within the municipal boundary of Helsinki (excluding the new Östersundom district) (Fig. 1). Since the respondents may mark multiple locations within one urban forest patch (hereafter referred to as patch), we counted marks from the same respondent in each patch only as 1. We use the number of marks from different respondents to indicate citizens' perceived uniqueness (PU) of urban forest. Note that the number of marks (i.e., PU) of a particular urban forest patch consists of marks from respondents who only marked one forest patch in their survey (more than 50% of respondents) as well as from respondents who marked multiple forest patches. As a result, respondents with multiple marks may have a higher impact than those with only one mark in our analyses. Yet, such a potential bias is very limited (see Supplement Fig. S2 and S3), as the number of respondents with multiple marks were relatively small.

Measuring biodiversity and environmental factors of each patch

Measuring biodiversity

No datasets are available to directly measure species diversity of each forest patch in Helsinki. However, there has been an open-access dataset kept by City of Helsinki called Natural Information System (referred to as "LTJ" in Finnish) (City of Helsinki, 2016), which recognizes important sites in terms of species richness and/or the occurrence of rare species for a specific taxonomic group (such as vascular plants, birds, bats and wood-inhabiting fungi) based on expert assessment and field observations. We used these data as an indirect indicator for biodiversity of each forest patch. To achieve this, we first extracted the important sites for four taxonomic groups from the LTJ dataset, respectively. The four taxonomic groups are vascular plant, bird, bat and wood-inhabiting fungal species (polypore), which are considered valuable in urban forests. Then, we overlapped these important sites with the urban forest patch map to identify whether each patch covers an important site of each taxonomic group (marked as "1" if yes and "0" if not for the patch). Consequently, for each patch, we have five biodiversity indicators (BDI): four binomial values (0 or 1) to indicate the biodiversity of each taxonomic group, and one summed value (0 to 4) of the four taxonomic groups to indicate "multi-taxa" biodiversity in each patch.

Measuring environmental factors

Three environmental factors, including vegetation structure, landscape features and surrounding urban context were evaluated for each patch using variables collected and calculated from various sources (Table 1).

It has been suggested by previous studies that openness and ground vegetation density, tree species composition, the size and age of trees, and diversity in forest characteristics are important factors affecting public preference for forest (Edwards et al., 2012). To quantify these features of the forest patches in this study, we used the multi-source Finnish National Forestry Inventory (MS-NFI) for 2013 which provided mean stand attributes, biomass and volume on 16 x 16 m grid data. Although the data have limited precision compared to field survey data, they cover the entire municipality of Helsinki, which allowed us to examine all urban forest patches at the city scale. For each urban forest patch, we took the mean value of canopy cover, stand height, stand diameter and stand age, summed the proportion of coniferous trees (in terms of the volumes of pines and spruces), and calculated Shannon's diversity index of the ground vegetation types (i.e., habitat diversity), which ranged from herb-rich forest to open rocky forest depending mostly on soil fertility (Tonteri, Hotanen, & Kuusipalo, 1990). Due to high correlations between some of the variables (see subsection "Statistical analysis" of Material and methods section, Supplementary material Fig. S4), we retained mean canopy cover, the proportion of broadleaved trees (the inverse of the proportion of coniferous trees) and habitat diversity, which reflected the potential influencing factors of openness, tree species composition, and diversity between forest stands respectively.

Patch size and connectivity were used to characterize landscape features of each patch. Forest patch size was calculated directly from the UGI map. Patch connectivity was calculated according to the Incidence Functional Model (IFM) (Hanski, 1994; Moilanen & Nieminen, 2002). In the original model, connectivity of a patch takes into account the size of the focal patch and its distance to surrounding patches. Because patch size has been considered a separate factor in our analysis, we excluded the focal patch area in the calculation to focus on connectivity that is solely determined by surrounding patches. More details on the calculation of patch connectivity are described in Supplementary material (section "Connectivity calculation").

To characterize the urban context of each patch, we used land-use intensity and population density in a 500 m buffer area around each patch. The 500 m buffer area was selected based on the accessibility of recreational urban greenspaces in Helsinki (Neuvonen et al., 2007). Land-use intensity is defined by the proportion of constructed land (buildings, roads and other constructed surfaces) in the buffer area. Population density was obtained from the same buffer area, and is defined by the number of persons per constructed land cover area in the buffer area according to Hahs & McDonnell (2006). Note that the conventional population density (i.e., the number of persons per area) was not used here because it is strongly correlated with land-use intensity. Both the land-use and population data are from the annual registration kept by the Helsinki metropolitan area (Helsinki Metropolitan Area Council, 2013). All spatial calculations of biodiversity and environmental factors were conducted using ArcGIS 10 (ESRI, 2011).

Statistical analysis

To explore the relationship between the perceived uniqueness (PU) of urban forests and the measured biodiversity and environmental factors, generalized linear models (GLM) were used. A high percentage (65%) of our response variable (i.e. number of respondents per patch) were zero values, which means that a great proportion of the patches were not marked by a single person in the PPGIS survey. Therefore, we employed a specialized GLM: the zero-inflated negative binomial GLM (ZINB-GLM), which considers all zero values while maintaining a relatively high fitness. The zero-inflated model employs an additional binomial model to explain the presence/absence of the counts (the binomial part), while variation in the counts (the count part) is explained by the negative binomial distribution (Zuur et al., 2009).

A total of 679 patches were included in the analysis after removing patches for which data of biodiversity and environmental factors are absent. Collinearity was checked before the ZINB-GLM analysis, and the criteria of variance inflation factor (VIF) < 3 was used to remove collinear explanatory variables (Zuur, Ieno, & Elphick, 2010). Eight variables (Table 1) were left for the ZINB-GLM analysis, among which, patch size and connectivity were log-transformed because the distribution of the two predictors are highly skewed. Model selection was further performed by removing variables of least explanatory power, one at a time, until the lowest Akaike information criterion (AIC) value was approached. The optimal model with its binomial (six variables left) and count (seven variables left) parts were used to explain the presence and variation of the PU of a patch, respectively. All GLM analyses were performed using R version 3.3.3 (R Core Team, 2016) with the pscl package (Jackman, 2015).

Additionally, we explored whether environmental factors can be indirectly associated with the PU of a patch through their impact on biodiversity indicators (BDIs). To disentangle such indirect relationships, we conducted piecewise structural equation modelling (SEM) (Shipley, 2009). SEM unites predictor and response variables in a single causal network containing a series of causal structures (namely, paths) that is represented by a set of linear (structured) equations using common GLM (Lefcheck, 2016). In this study, we constructed a SEM with two hypothesized paths: (1) The causal linkage between environmental factors (predictor) and BDIs (response), and (2) the causal linkage between BDIs/environmental factors (predictor) and the PU of each patch (response) (see Fig. 3). By building this SEM, we will be able to assess if environmental factors can affect the PU of urban forests indirectly through its impacts on BDIs (with Shipley's d-separation tests, see Supplementary material, section "SEM Analysis"). The piecewiseSEM package from R (version 1.2.1) was used for this analysis. More technical details on SEM are described in the Supplementary material.

Results

The perceived uniqueness (PU) of urban forest in Helsinki

Forests were most commonly perceived as unique urban nature in Helsinki. In the PPGIS survey, 2843 marks (59% of the total marks) by 895 respondents (64% of the total respondents) were recorded in urban forests (Fig. 1a). In comparison, public parks received only 709 (15% of the total) marks by 375 (26% of the total) respondents.

Counted as the number of respondents per patch, perceived uniqueness (PU) ranged from 0 to 128, and was distributed heterogeneously among the patches. As illustrated in Fig. 1, only a small portion of forest patches in the city are marked as unique urban nature (i.e., PU > 0), while almost 70% of the patches (n = 598) did not receive any marks. Variation among the marked patches (i.e. PU > 0) is also large: most patches received a low PU, while very few patches received a high PU (Fig. 1b). On average, PU of a patch is mainly from city-wide respondents rather than from respondents living in the same local district where the patch is located (Supplementary material, Fig. S1). The higher PU a patch has, the more the PU is from city-wide respondents, indicating that in general, PU reflects a city-wide perception of uniqueness and is not biased towards the perception of people from any local district.

The relationship between perceived uniqueness and measured biodiversity and environmental factors

Results of the count part of the optimal ZINB-GLM model (Table 2, Fig. 2a) shows that multi-taxa BDI had a significant positive correlation with PU of an urban forest, indicating that patches with higher species-level diversity are also perceived more unique by the public. Among the environmental factors, patch size had a dominant and significantly positive effect on PU, while patch connectivity correlated negatively, implying that less connected urban forest patches received a comparatively high uniqueness appreciation. The proportion of constructed land in surrounding area was negatively correlated with PU as expected, though the effect was marginally significant. Surrounding population density per constructed land was positively correlated with PU, indicating that the uniqueness of forest patches is perceived higher in densely populated areas. Canopy cover and habitat diversity were negatively correlated with PU.

The binomial part of the optimal ZINB-GLM model shows how biodiversity and environmental factors are correlated with the presence/absence of uniqueness perception in an urban forest patch (Table 2, Fig. 2b). Specifically, multi-taxa BDI is positively correlated with the presence/absence of uniqueness perception. The correlations of some environmental factors (e.g., patch size, patch connectivity and constructed land cover) are of the same sign in the binomial part as in the counts part of the model. In contrast, the correlation of canopy cover with PU exhibited an opposite sign in the binomial and counts parts of the model, implying a certain threshold of canopy cover has to be reached to be perceived as unique urban nature, but beyond the threshold, denser canopy cover might be less favorable as unique urban nature. Also note that population density and habitat diversity did not correlate significantly with PU in the binomial part, but did so with PU in the count part, while the opposite is true for the proportion of broadleaved trees.

The causal pathways between environmental factors and perceived uniqueness

We ran five piecewise SEMs with multi-taxa BDI and four single-taxon BDIs as mediator in the causal pathways, respectively. The Shipley's d-separation tests show that all SEMs fit the data well ($p > 0.05$, Supplementary material, SEM analysis, Table S1). The path diagram of the SEM using the multi-taxa BDI as mediator is illustrated in Fig. 3 (results of the other SEMs are shown in the Supplementary material, Tables S1, S2). We found that all five SEMs contained a path from the BDI to PU, except the one with polypore BDI as mediator. Most environmental factors (except patch connectivity) have a causal link to PU via BDIs (see also Supplementary material, Table S3), indicating a potential indirect impacts of environmental factors on PU through its effect on biodiversity. However, these indirect path coefficients (calculated as the product of path coefficients from environmental factors to BDI and from BDI to PU) were generally lower than those of the direct path (i.e., environmental factors to PU) (see Fig. 4), suggesting that the direct response of PU to environmental factors is more dominant. An exception is constructed land cover (i.e., land-used intensity), which had a much higher correlation with BDI than with PU, suggesting much higher sensitivity of BDI to surrounding constructed land cover than that of PU. As a result, the indirect effect of constructed land cover on PU through multi-taxa BDI is similar (or even higher for bird and bat BDI) to its direct effect on PU. The effects of environmental factors on BDI and PU are mostly in the same direction, expect for canopy cover. This highlights the distinct effect of canopy cover on biodiversity and on people's perception of unique urban nature.

Discussion

Do citizens perceive "unique urban nature" at important biodiversity sites?

The relationship between biodiversity and people's perceptions in urban greenspace has been found to be both positive (e.g., Fuller et al. 2007) and negative (e.g., Qui et al. 2013). Our results, based on city-wide survey data, support a positive correlation between biodiversity and citizens' perception of uniqueness in urban forests (Fig. 2). This indicates that people's perception of uniqueness and biodiversity can be compatible given one type of greenspace, i.e., urban forests. Moreover, although biodiversity might often be poorly perceived (Dallimer *et al.*, 2012; Rall *et al.*, 2017), our findings suggest that without mentioning biodiversity itself, citizens are able to identify urban forests of actual high biodiversity as having conservation priority in the participation process of urban planning.

Evidence has shown that the diversity of charismatic groups (e.g., birds, flowering plants, butterflies) (McGinlay et al., 2017; Unterweger, Schrode, & Betz, 2017) promote higher levels of benefits perceived by people. Through structural equation modeling, we found that the most pronounced taxonomic groups in citizens' conservation value are birds: patches that contain important sites for the diversity of birds are likely to be perceived as unique urban nature. On the contrary, the biodiversity of wood-inhibit fungi (polypore) seem not to be associated with PU of a patch. The presence of wood-inhabiting fungi usually indicates an abundance of deadwood, which is crucial for forest biodiversity (Jonsson, Kruys, & Ranius, 2005). The absence of the influence of this vital biodiversity feature on people's perceived conservation value indicates that people are indifferent towards deadwood in boreal forests, which is consistent with previous on-site studies (Hauru et al., 2014). People's different responses to multiple dimensions of biodiversity should be considered when conserving urban greenspace, and deserves further investigation.

How environmental factors affect biodiversity and perceived uniqueness of an urban forest patch?

The effects of landscape features

Our analysis indicates that patch size has a dominant positive relation with the PU of urban forests (Fig 2). This is similar to previous findings on urban parks that show an increase in human well-being (physical, psychological, environmental and social effects) (Brown, Schebella, & Weber, 2014; Nordh et al., 2009) with increasing size of urban parks, and suggest that people tend to attach higher conservation values to urban greenspace of larger size (no matter whether it's an urban park or a forest). In addition, the high PU of large patches may also be due to the popularity of these patches to the public, since people may ascribe a high level of ecosystem services to places they know even if they do not directly benefit from them (Kremer et al., 2016).

The effects of connectivity on biodiversity and the PU of urban ecosystems are complicated. From a biological perspective, connectivity among habitat patches facilitate species dispersal (Taylor et al., 1993), although the effects on urban species diversity is unclear (LaPoint et al., 2015; Prugh et al., 2008). From a human perspective, more connected forest patches are perceived as less unique urban nature, as found in our study (Fig 2). This is because forest patches with high connectivity in Helsinki are usually linear connections or "stepping stones" between larger patches, and thus are probably used by people as movement routes (see e.g., Brown *et al.*, 2014) but not perceived as unique urban nature. In contrast, isolated urban forest patches are those interspersed in the urban matrix, which has been reported to promote people's use and satisfaction because of their close proximity to people's lives and homes (Soga et al., 2015). The lower conservation value that urban residents assign to "stepping stone" forests pose a potential threat to the existence of such vital parts of the urban forest network.

Effects of the surrounding urban context

Current knowledge on the effects of the density of the surrounding built infrastructure has suggested that highly built urban areas will discourage the use of urban greenspace (Shanahan et al., 2017) and diminish the benefits of urban greenspace perceived by local residents (Luck et al., 2011). Our results are consistent with previous studies showing that a highly constructed surrounding decreases perceived conservation value of forests. This can be largely attributed to its negative impacts on biodiversity (especially bird and bat BDI) of the forest that locate there (Figs 3 and 4).

Previous studies have found that urban greenspaces located in lower residential density areas are associated with higher species diversity and higher ecosystem services provision (Latta et al., 2013; Tratalos et al., 2007). Contrary to the above, our results show a higher biodiversity indicator and PU of a patch located in high population density per constructed land-use surroundings. We attribute the concurrence of biodiversity and densely populated built areas to efforts of the City of Helsinki to preserve forest as a city-wide feature early in its history. As the city grew, areas surrounding these preserved forests developed into important residential areas inhabited densely by citizens. Moreover, higher conservation values given to these forests in the middle of dense residential areas also imply that high recreational demand in highly populated areas (Brander & Koetse, 2011) may have been widely acknowledged by citizens.

The effects of forest structure

Vegetation structure is a main factor influencing biodiversity and people's preference for forest (Johansson et al., 2014). Our results showed that canopy cover is positively correlated with biodiversity, but is negatively correlated with PU of an urban forest patch (Fig. 3). This indicates that even though high canopy cover is beneficial for maintaining the biodiversity of a forest patch, it may not be appreciated by people when it comes to the perception of unique nature. Such a discrepancy highlights a potential dilemma in canopy cover management of urban forests if the goal is to maximize both biodiversity and people's perceptions.

Previous studies on the effect of tree cover on recreational preference have demonstrated that people prefer urban forests with intermediate (rather than high) tree cover, and extremely dense canopy cover is not favoured by the general public (Edwards et al., 2012). The negative impact of over-dense canopy cover might come from a dense understory which are not preferred by people (Deng et al., 2014; Tomao et al., 2018). This may also explain the negative influence of canopy cover on PU shown in our results. In addition, we note that the higher PU of forest patches with less tree cover may also relate to the presence of open rocky areas, which are very common in Helsinki and highly favored by residents (Kopomaa, 2014).

We showed that habitat diversity of an urban forest patch is negatively correlated with PU, which is in contrast to previous understandings that a mixture of trees and variation between stands can promote the recreational value of forests (Filyushkina et al., 2017). This suggests that unlike structural variation (i.e., different tree species or height), different forest habitats (e.g. herb rich forest vs. mesic forest) might not be distinguishable or favored by people. These contrasting results imply that people's perception of forests is a result of complex human-nature relationships (Vierikko et al., 2016), and different vegetation measures have to be used to better model people's perceptions of urban forest.

Conclusions

Our results highlighted that citizens' perceptions of unique urban nature (i.e., conservation value) in Helsinki, measured by PPGIS, reflect a diverse urban natural preference, which does not only come from biodiversity factors of urban forests, but also to a large extent from people's direct response to the landscape features, vegetation structure and surrounding urban context of an urban forest patch. People's perceived uniqueness (PU) of an urban forest has a strong positive relation to biodiversity. Among environmental factors, size of an urban forest patch and surrounding population density of constructed areas have positive impacts on both biodiversity and PU, while connectivity, surrounding constructed land cover, and canopy cover of an urban forest patch exhibit a negative impact on PU. A significant indirect impact of these environmental factors on PU through their effects on biodiversity is detected by structural equation modelling, suggesting biodiversity is at the core of influencing people's perceptions of unique urban nature (i.e. conservation value). We also noticed that some environmental factors, such as connectivity and canopy cover, had distinct correlations with biodiversity and PU, highlighting a potential trade-off between biodiversity (natural conservation value) and PU (people's conservation value), which need to be balanced when planning or managing urban forests.

In the context of shrinking urban forests in Helsinki, protection has been voiced only for several "politically hot" forest patches. Our examination of the city-wide urban forest network provided a comprehensive understanding of what is perceived as worth conserving by the public. However, our findings hint that the influencing factors of this perceived conservation value differ greatly from that of the actual use of urban forest. Besides, we did not analyse the influence of PU by the respondents' background (i.e., the demand side), which are also important determinants of how people perceive urban greenspace (Unterweger, Schrode, & Betz, 2017). Future investigations could focus on comparing use, perception and valuation of urban greenspace, as well as analyzing people's background and motivations to identify human "niches" in urban greenspace networks.

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Reference

Beninde, J., Veith, M., & Hochkirch, A. (2015). Biodiversity in cities needs space : a meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters*, *18*(6), 581–592.

Brander, L. M., & Koetse, M. J. (2011). The value of urban open space: Meta-analyses of contingent valuation and hedonic pricing results. *Journal of Environmental Management*, *92*(10), 2763–2773.

Brown, G., & Fagerholm, N. (2015). Empirical PPGIS/PGIS mapping of ecosystem services: A review and evaluation. *Ecosystem Services*, *13*, 119–133.

Brown, G., Montag, J. M., & Lyon, K. (2012). Public Participation GIS: A Method for Identifying Ecosystem Services. *Society & Natural Resources*, *25*(7), 633–651.

Brown, G., Schebella, M. F., & Weber, D. (2014). Using participatory GIS to measure physical activity and urban park benefits. *Landscape and Urban Planning*, *121*, 34–44.

Buchel, S., & Frantzeskaki, N. (2015). Citizens' voice: A case study about perceived ecosystem services by urban park users in Rotterdam, the Netherlands. *Ecosystem Services*, *12*, 169–177.

Celis-Diez, J., Muñoz, C., Abades, S., Marquet, P., & Armesto, J. (2017). Biocultural Homogenization in Urban Settings: Public Knowledge of Birds in City Parks of Santiago, Chile. *Sustainability*, *9*(4), 485.

City of Helsinki. (2016). Nature Information System.

City of Helsinki. (2018). Continued population growth in Helsinki – 70 000 more residents in ten years.

Dearborn, D. C., & Kark, S. (2010). Motivations for Conserving Urban Biodiversity. *Conservation Biology*, *24*(2), 432–440.

Deng, S., Yin, N., Guan, Q., & Katoh, M. (2014). Dynamic response of the scenic beauty value of different forests to various thinning intensities in central eastern China. *Environmental Monitoring and Assessment*, *186*(11), 7413–7429.

Edwards, D., Jay, M., Jensen, F. S., Lucas, B., Marzano, M., Montagné, C., … Weiss, G. (2012). Preferences for structural attributes of forests : Towards a pan-European perspective. *Forest Policy and Economics*, *19*, 12–19.

ESRI. (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Faehnle, M., Bäcklund, P., Tyrväinen, L., Niemelä, J., & Yli-Pelkonen, V. (2014). How can residents' experiences inform planning of urban green infrastructure? Case Finland. *Landscape and Urban Planning*, *130*, 171–183.

Filyushkina, A., Agimass, F., Lundhede, T., Strange, N., & Bredahl, J. (2017). Preferences for variation in forest characteristics: Does diversity between stands matter? *Ecological Economics*, *140*, 22–29.

Fuller, R. a, Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, *3*(4), 390–394.

Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening*, *14*(4), 760–771.

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., … Elmqvist, T. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio*, *43*(4), 413–433.

Hahs, A. K., & McDonnell, M. J. (2006). Selecting independent measures to quantify Melbourne's urban-rural gradient. *Landscape and Urban Planning*, *78*, 435–448.

Hanski, I. (1994). A Practical Model of Metapopulation Dynamics. *Journal of Animal Ecology*, *63*(1), 151–162.

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health*, *35*(1), 207–228.

Hauru, K., Koskinen, S., Kotze, D. J., & Lehvävirta, S. (2014). The effects of decaying logs on the aesthetic experience and acceptability of urban forests - Implications for forest management. *Landscape and Urban Planning*, *123*, 114–123.

Helsinki Metropolitan Area Council. (2013). *SeutuCD'13*.

Ives, C. D., Oke, C., Hehir, A., Gordon, A., Wang, Y., & Bekessy, S. A. (2017). Capturing residents' values for urban green space: Mapping, analysis and guidance for practice. *Landscape and Urban Planning*, *161*, 32–43.

Jackman, S. (2015). {pscl}: Classes and Methods for {R} Developed in the Political Science Computational Laboratory, Stanford University. Stanford, California.

Johansson, M., Gyllin, M., Witzell, J., & Küller, M. (2014). Does biological quality matter? Direct and reflected appraisal of biodiversity in temperate deciduous broad-leaf forest. *Urban Forestry & Urban Greening*, *13*(1), 28–37.

Jonsson, B. G., Kruys, N., & Ranius, T. (2005). Ecology of species living on dead wood - Lessons for dead wood management. *Silva Fennica*, *39*(2), 289–309.

Kabisch, N., Qureshi, S., & Haase, D. (2015). Human–environment interactions in urban green spaces — A systematic review of contemporary issues and prospects for future research. *Environmental Impact Assessment Review*, *50*, 25–34.

Kahila-Tani, M., Broberg, A., Kyttä, M., & Tyger, T. (2016). Let the Citizens Map—Public Participation GIS as a Planning Support System in the Helsinki Master Plan Process. *Planning Practice & Research*, *31*(2), 195–214.

Kopomaa, T. (2014). *"Hetki suunnittelijana" - Public comments on the map survey of future Helsinki*. Helsinki.

Kremer, P., Hamstead, Z., Haase, D., Mcphearson, T., Frantzeskaki, N., Andersson, E., … Elmqvist, T. (2016). Key insights for the future of urban ecosystem services research. *Ecology and Society*, *21*(2), art29.

Kyttä, M., Broberg, A., Tzoulas, T., & Snabb, K. (2013). Towards contextually sensitive urban densification: Location-based softGIS knowledge revealing perceived residential environmental quality. *Landscape and Urban Planning*, *113*, 30–46.

LaPoint, S., Balkenhol, N., Hale, J., Sadler, J., & van der Ree, R. (2015). Ecological connectivity research in urban areas. *Functional Ecology*, *29*(7), 868–878.

Latta, S. C., Musher, L. J., Latta, K. N., & Katzner, T. E. (2013). Influence of human population size and the built environment on avian assemblages in urban green spaces. *Urban Ecosystems*, *16*(3), 463–479.

Lefcheck, J. S. (2016). piecewiseSEM: Piecewise structural equation modelling in r for ecology, evolution, and systematics. *Methods in Ecology and Evolution*, *7*(5), 573–579.

Lehvävirta, S., & Rita, H. (2002). Natural Regeneration of Trees in Urban Woodlands. *Journal of Vegetation Science*, *13*(1), 57–66.

Lin, B. B., Fuller, R. A., Bush, R., Gaston, K. J., & Shanahan, D. F. (2014). Opportunity or orientation? Who uses urban parks and why. *PLoS ONE*, *9*(1), 1–7.

Luck, G. W., Davidson, P., Boxall, D., & Smallbone, L. (2011). Relations between Urban Bird and Plant Communities and Human Well-Being and Connection to Nature. *Conservation Biology*, *25*(4), 816–826.

McGinlay, J., Parsons, D. J., Morris, J., Hubatova, M., Graves, A., Bradbury, R. B., & Bullock, J. M. (2017). Do charismatic species groups generate more cultural ecosystem service benefits? *Ecosystem Services*, *27*, 15–24.

Miller, J. R. (2005). Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution*, *20*(8), 430–434.

Moilanen, A., & Nieminen, M. (2002). Simple connectivity measures in spatial ecology. *Ecology*, *83*(4), 1131–1145.

Morelli, F., Benedetti, Y., Su, T., Zhou, B., Moravec, D., Šímová, P., & Liang, W. (2017). Taxonomic diversity, functional diversity and evolutionary uniqueness in bird communities of Beijing's urban parks: Effects of land use and vegetation structure. *Urban Forestry & Urban Greening*, *23*, 84–92.

Neuvonen, M., Sievänen, T., Tönnes, S., & Koskela, T. (2007). Access to green areas and the frequency of visits - A case study in Helsinki. *Urban Forestry and Urban Greening*, *6*, 235–247.

Nordh, H., Hartig, T., Hagerhall, C. M., & Fry, G. (2009). Components of small urban parks that predict the possibility for restoration. *Urban Forestry & Urban Greening*, *8*(4), 225–235.

Pett, T. J., Shwartz, A., Irvine, K. N., Dallimer, M., & Davies, Z. G. (2016). Unpacking the people-biodiversity paradox: A conceptual framework. *BioScience*, *66*(7), 576–583.

Prugh, L. R., Hodges, K. E., Sinclair, A. R. E., & Brashares, J. S. (2008). Effect of habitat area and isolation on fragmented animal populations. *Proceedings of the National Academy of Sciences*, *105*(52), 20770–20775.

R Core Team. (2016). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing.

Rall, E., Bieling, C., Zytynska, S., & Haase, D. (2017). Exploring city-wide patterns of cultural ecosystem service perceptions and use. *Ecological Indicators*, *77*, 80–95.

Saukkonen, T. (2011). *Helsingin kaupungin luononhoidon linjaus (Helsinki Nature Management Strategy)*. Helsinki, Finland: Public Works Department (in Finish).

Secretariat of the Convention on Biological Diversity. (2012). *Cities and Biodiversity Outlook — Action and policy*. *Montreal, Canada*.

Shanahan, D. F., Cox, D. T. C., Fuller, R. A., Hancock, S., Lin, B. B., Anderson, K., … Gaston, K. J. (2017). Variation in experiences of nature across gradients of tree cover in compact and sprawling cities. *Landscape and Urban Planning*, *157*, 231–238.

Shipley, B. (2009). Confirmatory path analysis in a generalized multilevel context. *Ecology*, *90*(2), 363–368.

Soga, M., & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment*, *14*(2), 94–101.

Soga, M., Yamaura, Y., Aikoh, T., Shoji, Y., Kubo, T., & Gaston, K. J. (2015). Reducing the extinction of experience: Association between urban form and recreational use of public greenspace. *Landscape and Urban Planning*, *143*, 69–75.

Suppakittpaisarn, P., Jiang, B., Slavenas, M., & Sullivan, W. C. (2018). Does density of green infrastructure predict preference? *Urban Forestry and Urban Greening*, (October 2017), 1–9.

Taylor, P. D., Fahrig, L., Henein, K., & Merriam, G. (1993). Connectivity Is a Vital Element of Landscape Structure. *Oikos*, *68*(3), 571–573.

Tomao, A., Secondi, L., Carrus, G., Corona, P., Portoghesi, L., & Agrimi, M. (2018). Restorative urban forests: Exploring the relationships between forest stand structure, perceived restorativeness and benefits gained by visitors to coastal Pinus pinea forests. *Ecological*

Indicators, *90*, 594–605.

Tonteri, T., Hotanen, J. P., & Kuusipalo, J. (1990). The Finnish forest site type approach: ordination and classification studies of mesic forest sites in southern Finland. *Vegetatio*, *87*(1), 85–98.

Tratalos, J., Fuller, R. a., Warren, P. H., Davies, R. G., & Gaston, K. J. (2007). Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning*, *83*, 308–317.

Tyrväinen, L., Mäkinen, K., & Schipperijn, J. (2007). Tools for mapping social values of urban woodlands and other green areas. *Landscape and Urban Planning*, *79*, 5–19.

Unterweger, P., Schrode, N., & Betz, O. (2017). Urban Nature: Perception and Acceptance of Alternative Green Space Management and the Change of Awareness after Provision of Environmental Information. A Chance for Biodiversity Protection. *Urban Science*, *1*(3), 24.

Vierikko, K., Elands, B., Niemelä, J., Andersson, E., Buijs, A., Fischer, L. K., … Konijnendijk van den Bosch, C. (2016). Considering the ways biocultural diversity helps enforce the urban green infrastructure in times of urban transformation. *Current Opinion in Environmental Sustainability*, *22*, 7–12.

Vierikko, K., Fors, H., & Saarinen, R. K. (2015). *Helsinki, Finland—Case Study City Portrait*.

Vierikko, K., Salminen, J., Niemelä, J., Jalkanen, J., & Tamminen, N. (2014). *Sustainable green infrastructure of Helsinki – urban ecological research report and recommendations for the Helsinki master plan 2014 (in Finnish with English summary)*.

Zhang, H., Chen, B., Sun, Z., & Bao, Z. (2013). Landscape perception and recreation needs in urban green space in Fuyang, Hangzhou, China. *Urban Forestry & Urban Greening*, *12*(1), 44–52.

Zuur, A. F., Ieno, E. N., & Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, *1*(1), 3–14.

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). Zero-truncated and zero-inflated models for count data. In *Mixed effects models and extensions in ecology with R* (pp. 261–293). Springer.

Appendix A. Supplementary material

See Supplementary material in the uploaded research data

Figures

see all full-sized figures in their original format in separate files

Figure 1. Perceived uniqueness (PU) of urban forest patches in Helsinki. a) Spatial distribution of urban forest patches (highlighted based on the land cover map) with associated PU (derived from the UGI map (Vierikko et al., 2014)). PU (based on the number of marks from different respondents) of urban forest patches are shown as different shades of green: the darker the color, the higher PU the patch has; patches with no perceived uniqueness marks are shown in white (see legend). b) PU from the highest rank to the lowest.

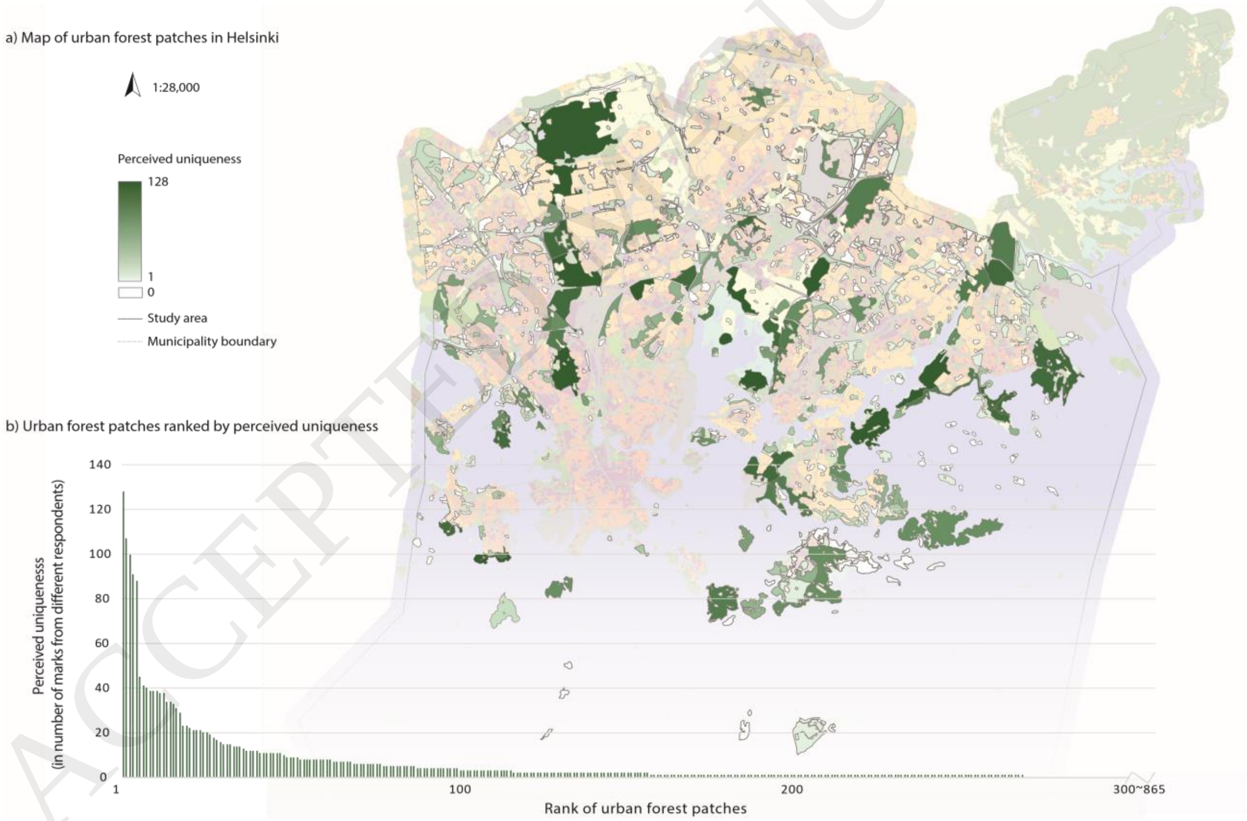


Figure 2. Standardized coefficients of environmental variables and multi-taxa BDI in the zero-inflated negative binomial GLM. The count and binomial parts are shown separately. Only effects of the variables that are significant (p-value < 0.05) are shown. Points are linear estimates ± 95% confidence intervals.

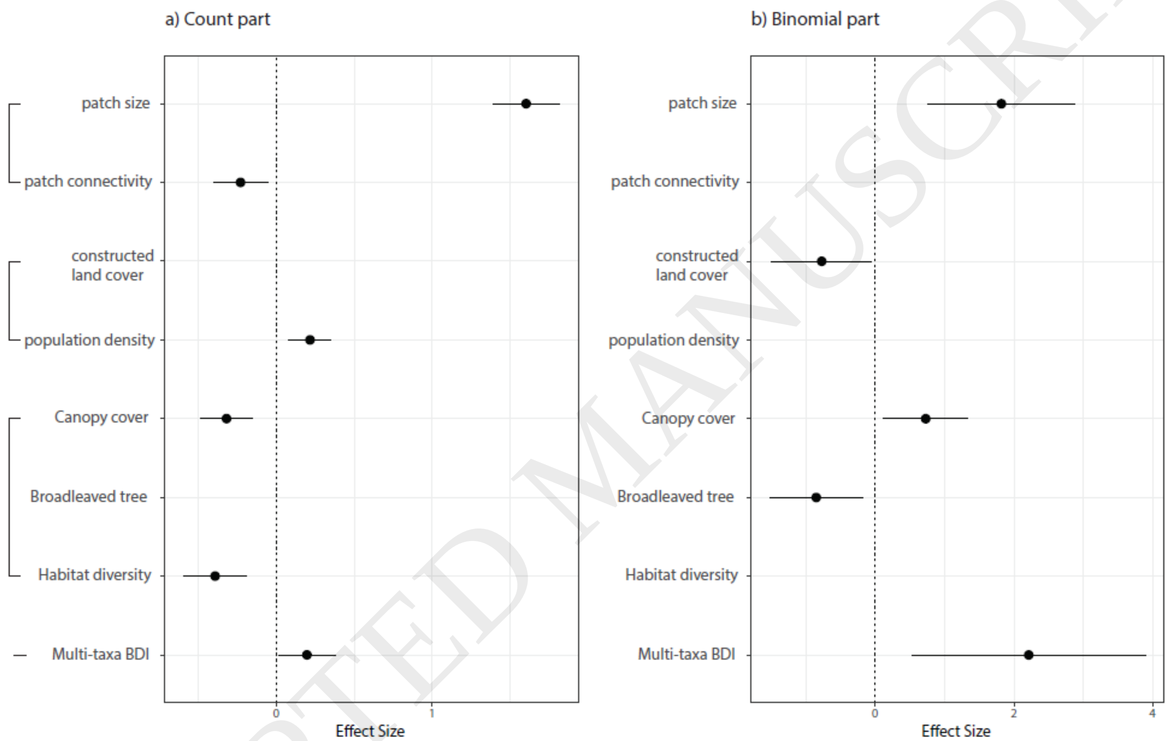


Figure 3. Path diagram of the structural equation model (SEM) using the multi-taxa biodiversity indicator as mediator. Solid (dashed) arrows between variables represent positive (negative) causal relationships (i.e., paths). The importance of each causal linkage (i.e., path) in contributing to the whole causal network between predictor and response variables as represented by standardized versions of linear regression weights (i.e., path coefficients) derived from each structured equation using common GLM, are shown on the arrows with the path significance shown with asterisks. Fisher's C statistic and p-values for Shipley's d-separation test are shown.

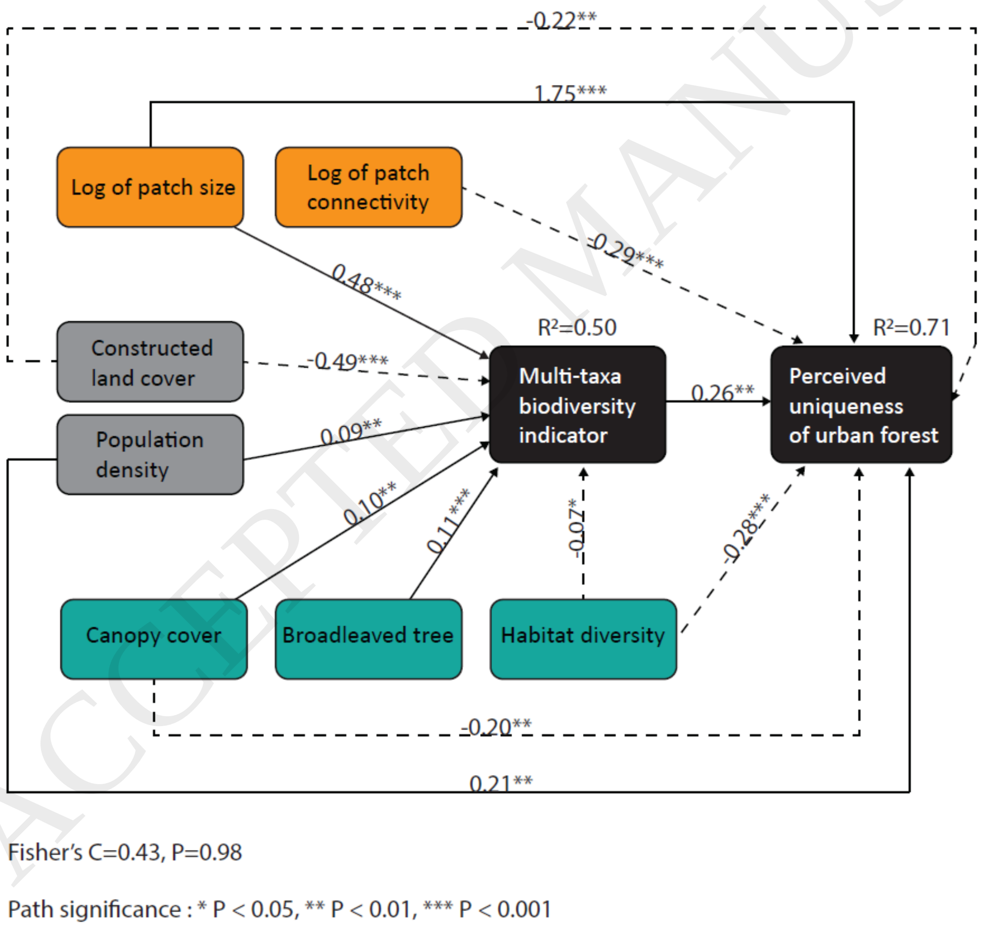
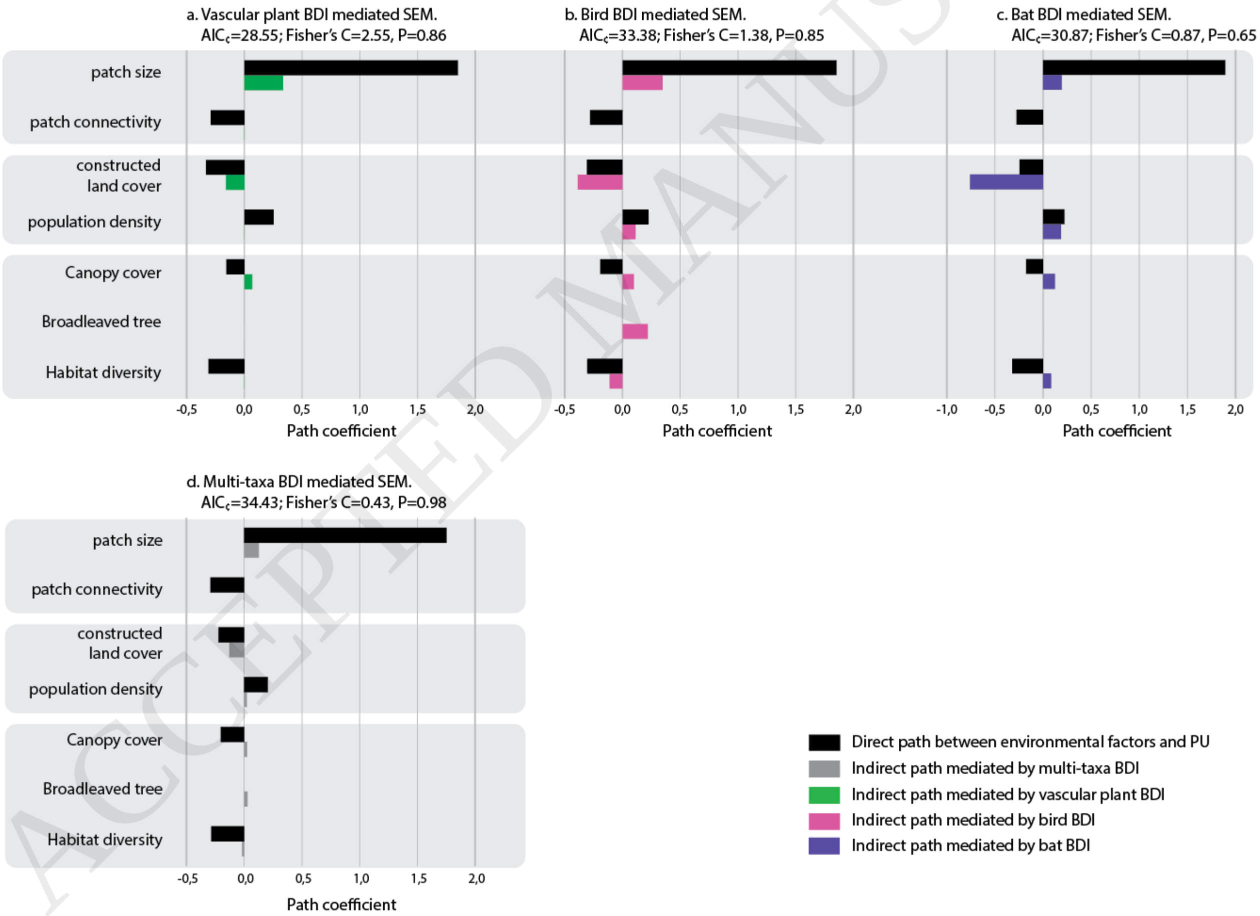


Figure 4: Path coefficients of direct and indirect paths between environmental variables and PU of urban forest patches in four SEMs: (a) vascular plant BDI mediated SEM, (b) bird BDI mediated SEM, (c) bat BDI mediated SEM, and (d) multi-taxa BDI mediated SEM. The path coefficients of significant direct paths in four SEMs are shown in black. The path coefficients of significant indirect paths are shown in different colors with different taxonomic groups (see legend). Fisher's C statistic and *p*-values for Shipley's d-separation test and AIC values are shown for all four models to indicate their goodness-of-fit.



Tables

Table 1. Urban forest patch variables used to model perceived uniqueness.

Variable	Data type	Data source
Biodiversity indicator		
Multi-taxa	Count	NI
Vascular plants	Binomial	NI
Birds	Binomial	NI
Bats	Binomial	NI
Polypores	Binomial	NI
Forest structure		
Broadleaved trees	Percentage	MS-NFI
Canopy cover	Percentage	MS-NFI
Habitat diversity	Continuous	MS-NFI
Landscape feature		
Patch size[1]	Continuous	UGI
Patch connectivity[1]	Continuous	UGI
Urban context		
Constructed land cover	Percentage	Seutu
Population density	Continuous	Seutu

Abbreviations: NI: Natural Information Map in Natural information system (LTJ), Environmental Protection Department of Helsinki, 2013; Seutu: Regional registration data, Helsinki Region Environmental Services Authority (HSY), 2013; MS-NFI: Multi-Source national forest inventories, Finish forest research institute (Luke), 2013; UGI: Urban Green Infrastructure Map, Helsinki, 2014. [1]: Patch size and connectivity were log transformed to obtain a balanced distribution.

Table 2. Results from the zero-inflated negative binomial GLM. Coefficients (Coeff), standard errors (SE) and *p*-values of significant variables are shown for both the Count and Binomial parts of the model.

	Count Part			Binomial Part		
	Coeff	SE	p-value	Coeff	SE	p-value
(Intercept)	-0.260	0.112	0.020	2.238	0.794	0.005
Multi-taxa BDI	0.195	0.094	0.037	2.212	0.860	0.010
Log of patch size	1.602	0.110	< 0.001	1.818	0.542	0.001
Log of patch connectivity	-0.231	0.088	0.009	-0.420	0.312	0.178
Constructed land cover	-0.106	0.084	0.206	-0.774	0.367	0.035
Population density	0.215	0.069	0.002	-	-	
Canopy cover	-0.321	0.085	< 0.001	0.726	0.310	0.019
Broadleaved trees	-	-	-	-0.853	0.342	0.013
Habitat diversity	-0.394	0.102	< 0.001	-	-	
Log(theta)	0.069	0.133	0.606			